

[0009] The actuator for the third articulation is disposed remotely, proximate the actuator for the second articulation in the hub thereof, to minimize the size and the weight of the third articulation. Accordingly, the second articulation hub is configured with two hubs nested on a common axis, namely the second axis.

[0010] In one embodiment, the three powered axes are also the three tracked axes of the haptic interface. In order to minimize the structural envelope of the haptic interface and maintain high resolution, an optical encoder is mounted on each of the three actuators proximate each capstan. Alternatively, actuators with integral encoders could be employed.

[0011] The haptic interface may also include automatic work volume calibration components for use in combination with computer software such that the haptic system, as a whole, has the capability to initialize position of the haptic interface and geometrically center the user reference point in both the workspace volume and virtual or remote environment.

[0012] Several other features may be provided in the haptic interface to enhance user safety and comfort. For example, a presence switch may be provided in the user connection element to indicate when the stylus is being grasped by a user. Alternatively or additionally, velocity limits may be provided for each of the powered axes to limit the speed of the axes. Lastly, a wrist rest or other structure may be provided to support a user's wrist and/or arm at a predetermined or adjustable height and orientation to address ergonomic concerns with prolonged or extended use of the haptic interface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention, in accordance with preferred and exemplary embodiments, together with further advantages thereof, is more particularly described in the following detailed description taken in conjunction with the accompanying drawings in which:

[0014] **FIG. 1** is a schematic perspective view of a force reflecting haptic interface in accordance with one embodiment of the present invention;

[0015] **FIG. 2A** is a schematic view of an automatic cable tensioning device useful in the haptic interface in accordance with one embodiment of the present invention;

[0016] **FIG. 2B** is a schematic plan view of the automatic cable tensioning device employed to drive the first articulation of the haptic interface in accordance with one embodiment of the present invention;

[0017] **FIG. 2C** is a schematic plan view of the automatic cable tensioning device employed to drive the second articulation of the haptic interface in accordance with one embodiment of the present invention;

[0018] **FIG. 2D** is a schematic plan view of a first automatic cable tensioning device employed to drive a transfer drive element of the third articulation of the haptic interface in accordance with one embodiment of the present invention;

[0019] **FIG. 2E** is a schematic plan view of a second automatic cable tensioning device employed on a reverse

side of the transfer drive element of the first automatic cable tensioning device depicted in **FIG. 2D** to drive the third articulation of the haptic interface;

[0020] **FIG. 3A** is a schematic cross-sectional view of a grounded actuator capstan for use in the cable drives of the haptic interface in accordance with an embodiment of the present invention;

[0021] **FIG. 3B** is a schematic side view of the grounded actuator capstan depicted in **FIG. 3A**;

[0022] **FIG. 4A** is a schematic perspective view of a transfer drive for powering the third articulation of the haptic interface in accordance with one embodiment of the present invention;

[0023] **FIG. 4B** is a schematic enlarged perspective view of a portion of the transfer drive depicted in **FIG. 4A**;

[0024] **FIG. 5** is a schematic side view of an actuator with an encoder disposed proximate the cable drive capstan for use in the haptic interface in accordance with an embodiment of the present invention;

[0025] **FIG. 5A** is an enlarged schematic view of a portion of the cable drive capstan depicted in **FIG. 5** for use in the haptic interface in accordance with an embodiment of the present invention;

[0026] **FIG. 6** is a schematic cross-sectional view of a presence switch integrated into the user connection stylus element of the haptic interface in accordance with an embodiment of the present invention;

[0027] **FIG. 7** is a schematic of a portion of the circuit board disposed in the stylus depicted in **FIG. 6**, including the presence switch circuitry;

[0028] **FIG. 8A** is a schematic side view of an ergonomic representation of a user employing the haptic interface in combination with a wrist rest in a desktop environment;

[0029] **FIG. 8B** is a schematic top view of the ergonomic representation depicted in **FIG. 8A**; and

[0030] **FIGS. 9A-9D** are schematic top, side, end section, and partial section views of a wrist rest for use in combination with the haptic interface in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0031] **FIG. 1** is a schematic perspective view of a six degree of freedom force reflecting haptic interface **10** in accordance with one embodiment of the present invention. The interface **10** includes a housing **12** defining a reference ground, six joints or articulations, and six structural elements. A first powered tracked rotary element **14** is supported by the housing **12** to define a first articulation **16** with an axis "A" having a substantially vertical orientation. A second powered tracked rotary element **18** is mounted thereon to define a second articulation **20** with an axis "B" having a substantially perpendicular orientation relative to the first axis, A. A third powered tracked rotary element **22** is mounted on a generally outwardly radially disposed extension **24** of the second element **18** to define a third articulation **26** having an axis "C" which is substantially parallel to the second axis, B. A fourth free rotary element **28** is mounted on a generally outwardly radially disposed